Lake and Wetland Monitoring Program

2003 Annual Report

By

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Executive Summary

The Kansas Department of Health and Environment (KDHE) Lake and Wetland Monitoring Program surveyed the water quality conditions of 36 Kansas lakes and wetlands during 2003. Nine of the lakes surveyed were large federal impoundments, eight were State Fishing Lakes (SFLs), six were units within the Mined Land Lakes Recreation Area, 10 were city and county lakes, and three were state or federally owned and managed wetland areas .

Of the 36 lakes and wetlands surveyed, 47% indicated trophic state conditions comparable to their historic mean water quality conditions. Another 31% indicated improved water quality conditions, over mean historic condition, as evidenced by a lowered lake trophic state. The remaining 22% indicated degraded water quality, over historic mean condition, as evidenced by elevated lake trophic state conditions. Phosphorus was identified as the primary factor limiting phytoplankton growth in 42% of the lakes surveyed during 2003. Nitrogen was identified as the primary limiting factor in 28% of the lakes, while <3% were identified as primarily light limited. The remaining lakes and wetlands appeared limited by combinations of nutrients or nutrients and light availability (17%), micronutrient limitation (6%), hydrologic flushing rate (<3%), or competition with the macrophyte community (<3%).

There were a total of 148 documented exceedences of Kansas numeric and narrative water quality criteria, or Environmental Protection Agency (EPA) water quality guidelines, in the lakes surveyed during 2003. Of these 148 exceedences, 30% pertained to the aquatic life use and 70% concerned consumptive and recreational uses. Fully 61% involved uses previously designated in the Kansas Surface Water Register. Approximately 39% were for uses that had not been formally designated or verified by use attainability analyses.

Nineteen lakes and wetlands (53% of those surveyed for pesticides) had detectable levels of at least one pesticide in their main bodies during 2003. Atrazine, or its degradation byproduct deethylatrazine, were detected in all 19 of these waterbodies, once again making atrazine the most commonly documented pesticide in Kansas lakes. Owing in large part to reduced runoff and inflow during the current multiple year drought, no lake during 2003 exceeded the water supply criterion for atrazine. However, drought does not seem to have had much effect, over the last few years, on the percentage of lakes that have detectable pesticides within their water columns. Percentage of lakes with pesticides, over the most recent four years (2000-2003) ranged from 53-62% and averaged 58.5%. The previous four years (1996-1999) ranged from 51-70% of lakes with detectable pesticides, and averaged 58.8%. A total of five different pesticides, and one pesticide degradation byproduct, were found in lakes during 2003.

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Of the 36 lakes and wetlands surveyed, 47% indicated moderate conditions comparable to their historic mean water quality conditions. Another 31% indicated improved water quality conditions over historic conditions, as evidenced by lowered lake trophic state. The remaining 22% indicated degraded water quality over historic mean conditions, as evidenced by elevated lake trophic state conditions. Phosphorus was identified as the primary factor limiting phytoplankton growth in 42% of the lakes surveyed during 2003. Nitrogen was identified as the primary limiting factor in 28% of the lakes, while 8% were identified as primarily light limited. The remaining lakes or wetlands were primarily limited by combinations of nutrients or light availability (17%), zooplankton limitation (6%), hydrologic flushing rate (<3%), or competition with the macrophyte community (<3%).

There were a total of 148 documented exceedences of Kansas numeric and narrative water quality criteria, or Environmental Protection Agency (EPA) water quality guidelines, in the lakes surveyed during 2003. Of these 148 exceedences, 33% pertained to the Aquatic Life use and 17% concerned consumptive and recreational uses. Only 24% involved uses previously designated in the Kansas Surface Water Register. Approximately 38% were for uses that had not been formally designated or verified by use attainability analyses.

Nineteen lakes and wetlands (53% of those surveyed) had detectable levels of at least one pesticide in their water column during 2003. Atrazine, or its degradation by-product deethylatrazine, were detected in all 19 of these water bodies, once again making atrazine the most commonly documented pesticide in Kansas lakes. Owing, in large part to reduced runoff and inflow during the current multiple year drought, the lake data in 2003 [illegible]. However, drought does not seem to have had much, in fact, over the last few years, on the percentage of lakes that have detectable pesticides within the water column. Percentages of lakes with detectable pesticides over the most recent four years (2000-2003) ranged from 53-72% and averaged 61.5%. The previous four years (1996-1999) ranged from 57-70% of lakes with detectable pesticides, and averaged 63.8%. A total of five different pesticides, and one pesticide degradation byproduct, were found in lakes during 2003.

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INTRODUCTION

Development of the Lake and Wetland Monitoring Program

The Kansas Department of Health and Environment (KDHE) Lake and Wetland Monitoring Program was established in 1975 to fulfill the requirements of the 1972 Clean Water Act (Public Law 92-500) by providing Kansas with background water quality data for water supply and recreational impoundments, determining regional and time trends for those impoundments, and identifying pollution control and/or assessment needs within individual lake watersheds.

Program activities originally centered around a small sampling network comprised mostly of federal lakes, with sampling stations at numerous locations within each lake. In 1985, based on the results of statistical analyses conducted by KDHE, the number of stations per lake was reduced to a single station within the main body of each impoundment. This, and the elimination of parameters with limited interpretive value, allowed expansion of the lake network to its present 121 sites scattered throughout all the major drainage basins and physiographic regions of Kansas. The network remains dynamic, with lakes occasionally being dropped from active monitoring and/or replaced with more appropriate sites throughout the state.

In 1989, KDHE initiated a Taste and Odor/Algae Bloom Technical Assistance Program for public drinking water supply lakes. This was done to assist water suppliers in the identification and control of taste and odor problems in finished drinking water that result from pollution, algae blooms, or natural ecological processes.

Overview of the 2003 Monitoring Activities

Staff of the KDHE Lake and Wetland Monitoring Program visited 36 Kansas lakes and wetlands during 2003. Nine of these water bodies are large federal impoundments last sampled in 2000 or as part of special projects, eight are State Fishing Lakes (SFLs), 10 are city/county lakes (CLs and Co. lakes, respectively), three are wetlands, and six are units in the Mined Land Lakes Recreation Area. Fourteen of the 36 lakes (39%) serve as either primary or back-up municipal or industrial water supplies.

General information on the lakes surveyed during 2003 is compiled in Table 1. Figure 1 depicts the locations of the lakes surveyed in 2003. Figure 2 depicts the locations of all currently active sites within the Lake and Wetland Monitoring Program. Additionally, a total of six lakes, streams, and ponds were investigated as part of the Taste and Odor/Algae Bloom Technical Assistance Program. Created lakes are usually termed "reservoirs" or "impoundments," depending on whether they are used for drinking water supply or for other beneficial uses, respectively. In many parts of the country, smaller lakes are termed "ponds" based on arbitrary surface area criteria. To provide consistency, this report uses the term "lake" to describe all non-wetland bodies of standing water within the state. The only exception to this is when more than one lake goes under the same general name. For example, the City of Herington has jurisdiction over two larger lakes. The older lake is referred to as Herington City Lake while the newer one is called

Herington Reservoir in order to distinguish it from its sister waterbody.

METHODS

Yearly Selection of Monitored Sites

Since 1985, the 24 large federal lakes in Kansas have been arbitrarily partitioned into three groups of eight. Each group is normally sampled only once during a three year period of rotation. Up to 30 smaller lakes are sampled each year in addition to that year's block of eight federal lakes. These smaller lakes are chosen based on three considerations: 1) Are there recent data available (within the last 3-4 years) from KDHE or other programs?; 2) Is the lake showing indications of pollution that require enhanced monitoring?; or 3) Have there been water quality assessment requests from other administrative or regulatory agencies (state, local, or federal)? Several lakes have been added to the network due to their relatively unimpacted watersheds. These lakes serve as ecoregional reference, or "least impacted," sites.

Sampling Procedures

At each lake, a boat is anchored over the inundated stream channel near the dam. This point is referred to as Station 1, and represents the area of maximum depth. Duplicate water samples are taken by Kemmerer sample bottle at 0.5 meters below the surface for determination of basic inorganic chemistry (major cations and anions), algal community composition, chlorophyll-a, nutrients (ammonia, nitrate, nitrite, Kjeldahl nitrogen, total organic carbon, and total and ortho phosphorus), and total recoverable metals/metalloids (aluminum, antimony, arsenic, barium, beryllium, cadmium, chromium, cobalt, copper, iron, lead, manganese, mercury, molybdenum, nickel, selenium, silver, thallium, vanadium, and zinc). Duplicate water samples are also taken at 0.5 to 1.0 meters above the lake substrate for determination of inorganic chemistry, nutrients, and metals/metalloids within the hypolimnion. In addition, a single pesticide sample, and duplicate fecal coliform bacteria samples, are collected at 0.5 meters depth at the primary sampling point (KDHE, 2000).

At each lake, measurements are made at Station 1 for temperature and dissolved oxygen profiles, field pH, photosynthetically active radiation (PAR) extinction, and Secchi disk depth. All samples are preserved and stored in the field in accordance with KDHE quality assurance/quality control protocols (KDHE, 2000). Field measurements, chlorophyll-a analyses, and algal taxonomic determinations are conducted by staff of KDHE's Bureau of Environmental Field Services. All other analyses are carried out by the KDHE Health and Environmental Laboratory (KHEL) (KDHE, 1995).

Table 1. General information pertaining to lakes surveyed during 2003.

Lake	Basin	Authority	Water Supply	Last Survey
Augusta Santa Fe Lake	Walnut	City	yes	2000
Banner Creek Lake	Kansas/Lower Republican	County	yes	1999
Butler Co. SFL	Walnut	State	no	2000
Cedar Bluff Lake	Smoky Hill/Saline	Federal	no	2000
Chanute Santa Fe Lake	Neosho	City	no	2000
Chase Co. SFL	Neosho	State	no	2000
Cheyenne Bottoms	Lower Arkansas	State	no	2000
Clinton Lake	Kansas/Lower Republican	Federal	yes	2000
Fort Scott Lake	Marais des Cygnes	City	yes	2000
Herington Reservoir	Smoky Hill/Saline	City	yes	2000
Hillsdale Lake	Marais des Cygnes	Federal	yes	2002
Jewell Co. SFL	Solomon	State	no	1999
Kanopolis Lake	Smoky Hill/Saline	Federal	yes	2000
Lake Kahola	Neosho	City	yes	1999
Lake Shawnee	Kansas/Lower Republican	City	no	1999
Lone Star Lake	Kansas/Lower Republican	County	no	2000
Miami Co. SFL	Marais des Cygnes	State	no	1996
Milford Lake	Kansas/Lower Republican	Federal	yes	2000
Mined Land Lake 6	Neosho	State	no	1999
Mined Land Lake 7	Neosho	State	no	1999
Mined Land Lake 12	Neosho	State	no	2000
Mined Land Lake 17	Neosho	State	no	1999
Mined Land Lake 27	Neosho	State	no	2000
Mined Land Lake 30	Neosho	State	no	2000
Ottawa Co. SFL	Solomon	State	no	1999
Perry Lake	Kansas/Lower Republican	Federal	yes	2000
Pleasanton Reservoir	Marais des Cygnes	City	yes	2000

Lake	Basin	Authority	Water Supply	Last Survey
Polk Daniels SFL	Verdigris	State	yes	1999
Pony Creek Lake	Missouri	City	yes	2000
Quivera Big Salt Marsh	Lower Arkansas	Federal	no	2000
Quivera Little Salt Marsh	Lower Arkansas	Federal	no	2000
Shawnee Co. SFL	Kansas/Lower Republican	State	no	2000
Tuttle Creek Lake	Kansas/Lower Republican	Federal	yes	2000
Washington Co. SFL	Kansas/Lower Republican	State	no	1999
Webster Lake	Solomon	Federal	no	2000
Wilson Lake	Smoky Hill/Saline	Federal	no	2000

Since 1992, macrophyte surveys have been conducted at each of the smaller lakes (<300 acres) within the KDHE Lake and Wetland Monitoring Program network. These surveys entail the selection and mapping of 10 to 20 sampling points, depending on total surface area and lake morphometry, distributed in a regular pattern over the lake surface. At each sampling point, a grappling hook is cast to rake the bottom for submersed aquatic plants. This process, combined with visual observations at each station, confirms the presence or absence of macrophytes at each station. If present, macrophyte species are identified and recorded on site. Specimens that cannot be identified in the field are placed in labeled plastic bags, on ice, for identification at the KDHE Topeka office. Presence/absence data, and taxon specific presence/absence data, are used to calculate spacial coverage (percent distribution) estimates for each lake (KDHE, 2000).

<u>Taste and Odor/Algae Bloom Program</u>

In 1989, KDHE initiated a formal Taste and Odor/Algae Bloom Technical Assistance Program. Technical assistance concerning taste and odor incidences in water supply lakes, or algae blooms in lakes and ponds, may take on varied forms. Investigations are generally initiated at the request of water treatment plant personnel, or personnel at the KDHE district offices. While lakes used for public water supply are the primary focus, a wide variety of samples related to algae, odors, and fishkills, from both lakes and streams, are accepted for analysis.

Figure 1. Locations of the 36 lakes surveyed during 2003.

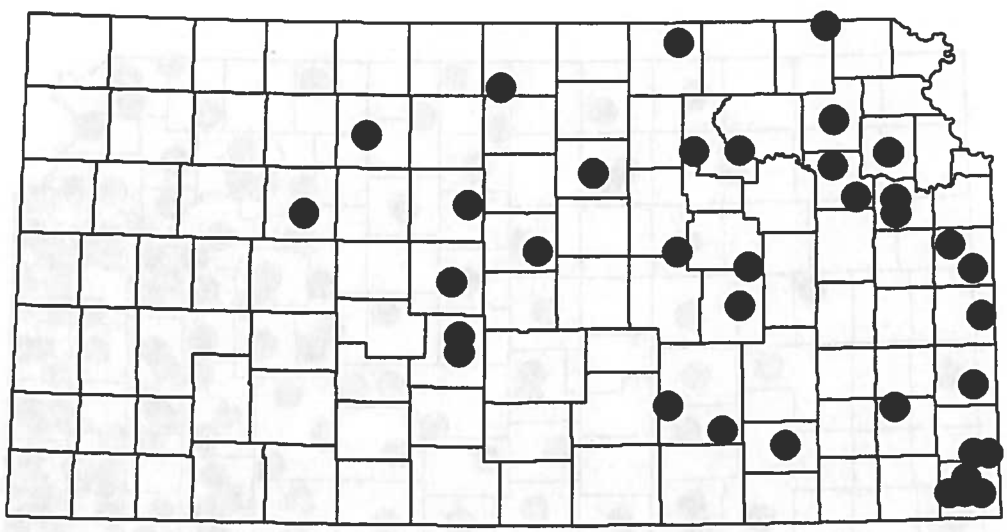
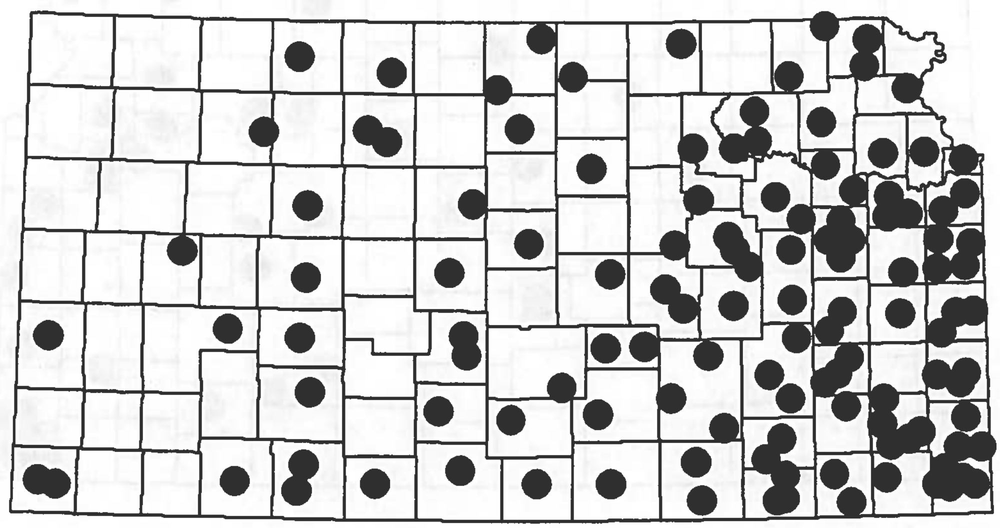


Figure 2. Locations of all currently active lake and wetland sampling sites within the KDHE Lake and Wetland Monitoring Program.



RESULTS AND DISCUSSION

Lake Trophic State

The Carlson Chlorophyll-a Trophic State Index (TSI) provides a useful tool for the comparison of lakes in regard to general ecological functioning and level of productivity (Carlson, 1977). Table 2 presents TSI scores for the 36 lakes surveyed during 2003, previous TSI mean scores for those lakes with past data, and an indication of the extent that lake productivity is dominated by submersed and floating-leaved vascular plant communities (macrophytes). Since chlorophyll-a TSI scores are based on the planktonic algae community, production due to macrophyte beds is not reflected in these scores. The system used to assign lake trophic state, based on TSI scores, is presented below. Trophic state classification is adjusted for macrophytes where percent areal cover (as estimated by percent presence) is greater than 50%, and visual bed volume and plant density clearly indicate that macrophyte productivity contributes significantly to overall lake primary production.

TSI score of 0-39 = oligo-mesotrophic (OM)

> OM = A lake with a low level of planktonic algae. Such lakes also lack significant amounts of suspended clay particles in the water column, giving them a relatively high level of water clarity. Chlorophyll-a concentration averages no more than 2.5 ug/L.

TSI score of 40-49 = mesotrophic (M)

> M = A lake with only a moderate planktonic algal community. Water clarity remains relatively high. Chlorophyll-a ranges from 2.51 to 7.2 ug/L.

TSI score of 50-63 = eutrophic (E)

> E = A lake with a moderate-to-large algae community. Chlorophyll-a ranges from 7.21 to 30.0 ug/L. This category is further divided as follows:

TSI = 50-54 = slightly eutrophic (SE)	Chlorophyll-a ranges 7.21 to 12.0 ug/L,
TSI = 55-59 = fully eutrophic (E)	Chlorophyll-a ranges 12.01 to 20.0 ug/L,
TSI = 60-63 = very eutrophic (VE)	Chlorophyll-a ranges 20.01 to 30.0 ug/L.

TSI score of $\geq$64 = hypereutrophic (H)

H = A lake with a very large phytoplankton community. Chlorophyll-a averages more than 30.0 ug/L. This category is further divided as follows:

TSI = 64-69.9 = lower hypereutrophic   Chlorophyll-a ranges 30.01 to 55.99 ug/L,
TSI = $\geq$70 = upper hypereutrophic   Chlorophyll-a values $\geq$56 ug/L.

TSI score not relevant = argillotrophic (A)

A = In a number of Kansas lakes, high turbidity due to suspended clay particles restricts the development of a phytoplankton community. In such cases, nutrient availability remains high, but is not fully translated into algal productivity or biomass due to light limitation. Lakes with such high turbidity and nutrient levels, but lower than expected algal biomass, are called argillotrophic (Naumann, 1929) rather than oligo-mesotrophic, mesotrophic, etc. These lakes may have chronically high turbidity, or may only experience sporadic (but frequent) episodes of dis-equilibrium following storm events that create "over flows" of turbid runoff on the lake surface. Frequent wind resuspension of sediments, as well as benthic feeding fish communities (e.g., common carp), can create these conditions as well. Argillotrophic lakes also tend to have very small, or nonexistent, submersed macrophyte communities. Mean chlorophyll-a concentration does not exceed 7.2 ug/L as a general rule.

All Carlson chlorophyll TSI scores are calculated by the following formula, where C is the phaeophytin corrected chlorophyll-a level in ug/L (Carlson, 1977):

$$TSI = 10(6-(2.04-0.68\log_e(C))/\log_e(2)).$$

The composition of the algal community (structural feature) often gives a better ecological picture of a lake than relying solely on a trophic state classification (functional feature). Table 3 presents both total algal cell count and percent composition of several major algal groups for the lakes surveyed in 2003. Lakes in Kansas that are nutrient enriched tend to be dominated by green or blue-green algae, while those dominated by diatom communities may not be so enriched. Certain species of green, blue-green, diatom, or dinoflagellate algae may contribute to taste and odor problems in finished drinking water, when present in large numbers in lakes and streams. The mean algal cell count among the 36 lakes this year was 45,276 cells/mL (median = 13,388 cells/mL).

Table 4 presents biovolume data for the 36 lakes surveyed in 2003. When compared to cell counts, such data are useful in determining which species or algae groups actually exert the strongest ecological influence on a lake. The mean algal biovolume among lakes this year was 25.1 ppm (median = 9.8 ppm).

Table 2. Current and past TSI scores, and trophic state classification for the lakes surveyed during 2003. Trophic class abbreviations used previously apply. An asterisk appearing after the lake name indicates that the lake was dominated, at least in part, by macrophyte production. In such a case, the trophic class is adjusted, and the adjusted trophic state class given in parentheses. Previous TSI scores are based only on algal chlorophyll TSI score.

Lake	2003 TSI/Class	Previous Trophic Class Period of Record Mean
Augusta Santa Fe Lake	57.1 E	E
Banner Creek Lake	52.2 SE	E
Butler Co. SFL	78.0 H	H
Cedar Bluff Lake	51.3 SE	E
Chanute Santa Fe Lake	63.6 VE	H
Chase Co. SFL	49.7 M	SE
Cheyenne Bottoms	76.3 H	H
Clinton Lake	65.1 H	E
Fort Scott Lake	46.7 M	SE
Herington Reservoir	60.0 VE	VE
Hillsdale Lake$	59.0 E	E
Hillsdale Lake Sta. 1 (Main Body)	55.7 E	SE
Hillsdale Lake Sta. 2 (Big Bull Creek Arm)	62.1 VE	E
Hillsdale Lake Sta. 3 (Little Bull Creek Arm)	58.3 E	E
Jewell Co. SFL	65.3 H	VE
Kanopolis Lake	57.2 E	SE
Lake Kahola	54.1 SE	SE
Lake Shawnee	62.4 VE	E
Lone Star Lake	51.1 SE	E
Miami Co. SFL*	56.8 E (VE)	H
Milford Lake	57.5 E	SE
Mined Land Lake 6	83.4 H	H
Mined Land Lake 7*	38.5 OM (M)	M

Lake	2003 TSI/Class	Previous Trophic Class Period of Record Mean
Mined Land Lake 12*	29.5 OM (M)	OM
Mined Land Lake 17*	37.9 OM (M)	OM
Mined Land Lake 27*	42.7 M (SE)	M
Mined Land Lake 30*	33.5 OM (M)	OM
Ottawa Co. SFL*	63.5 VE (VE)	VE
Perry Lake	53.8 SE	SE
Pleasanton Reservoir	65.1 H	E
Polk Daniels SFL	59.5 E	E
Pony Creek Lake	51.7 SE	VE
Quivera Big Salt Marsh	61.3 VE	H
Quivera Little Salt Marsh	58.3 E	H
Shawnee Co. SFL	50.9 SE	SE
Tuttle Creek Lake	50.0 A	A
Washington Co. SFL	60.6 VE	E
Webster Lake	61.2 VE	E
Wilson Lake	46.1 M	M

$ = Hillsdale Lake's whole lake TSI is the mean of three individual stations within the lake.

Trends in Trophic State

Table 5 summarizes changes in trophic status for the 36 lakes surveyed during 2003. Eight lakes (22.2%) displayed increases in trophic state, compared to their historic mean condition, while 11 lakes (30.6%) displayed improved trophic states. Stable conditions were noted in 17 lakes (47.2%).

In general, lakes strongly influenced by nutrient inputs improved in water quality this year and last year, while some of those noted as light limited in the past seemed to have higher trophic state conditions and less turbidity. The drought conditions of the last couple years, and the reductions in runoff and the nutrients carried in runoff, would seem to have exerted some impact on water quality. Lakes historically identified as light limited but having strong internal components creating high turbidity (i.e., sizeable common carp populations or wind mixing) did not improve to any significant degree.

Table 3. Algal communities observed in the 36 lakes surveyed during 2003. The "other" category refers to euglenoids, cryptophytes, dinoflagellates, and other single-celled flagellate groups of algae.

Lake	Cell Count (cells/mL)	Percent Composition			
		Green	Blue-Green	Diatom	Other
Augusta Santa Fe Lake	8,348	6	67	21	6
Banner Creek Lake	13,388	10	88	0	2
Butler Co. SFL	390,317	<1	98	<2	<1
Cedar Bluff Lake	11,120	51	37	9	3
Chanute Santa Fe Lake	13,797	40	0	48	12
Chase Co. SFL	3,402	<2	92	<2	5
Cheyenne Bottoms	150,602	58	40	1	1
Clinton Lake	11,592	<1	78	6	15
Fort Scott Lake	6,741	27	70	1	2
Herington Reservoir	9,797	29	8	51	12
Hillsdale Lake (mean)	27,794	5	89	6	<1
Hillsdale Lake Sta. 1	24,759	2	95	3	<1
Hillsdale Lake Sta. 2	32,823	5	86	8	1
Hillsdale Lake Sta. 3	25,799	7	85	8	<1
Jewell Co. SFL	22,050	19	76	<1	4
Kanopolis Lake	11,025	30	51	10	9
Lake Kahola	6,111	48	29	10	13
Lake Shawnee	44,888	7	90	3	<1
Lone Star Lake	14,144	4	91	3	2
Miami Co. SFL	38,052	8	91	1	0
Milford Lake	24,224	16	83	<1	<1
Mined Land Lake 6	482,391	0	99	<1	1
Mined Land Lake 7	5,513	6	91	<1	3
Mined Land Lake 12	3,875	8	88	2	2

Lake	Cell Count (cells/mL)	Percent Composition			
		Greens	Blue-Greens	Diatoms	Other
Mined Land Lake 17	945	77	0	9	14
Mined Land Lake 27	7,560	5	94	0	1
Mined Land Lake 30	3,497	6	93	<1	1
Ottawa Co. SFL	29,642	43	56	<1	<1
Perry Lake	5,954	17	49	31	3
Pleasanton Reservoir	58,086	27	51	21	1
Polk Daniels SFL	24,633	10	85	3	2
Pony Creek Lake	9,261	4	86	7	3
Quivera Big Salt Marsh	70,812	18	78	3	1
Quivera Little Salt Marsh	9,702	77	0	16	7
Shawnee Co. SFL	4,505	85	0	<1	14
Tuttle Creek Lake	5,261	19	72	0	9
Washington Co. SFL	13,608	25	53	14	8
Webster Lake	45,329	15	80	3	2
Wilson Lake	2,930	39	39	17	5

As shown in Table 6, of the 22 lakes receiving macrophyte surveys (20 full surveys and 2 limited observational surveys), 16 (73% of those surveyed, 44% of all lakes in 2003) had detectable amounts of submersed plant material. In these lakes, the most common plant species were pondweeds (Potamogeton spp.), water naiad (Najas guadalupensis), coontail (Ceratophyllum demersum), parrot feather (Myriophyllum spicatum), and various species of stonewort algae (Chara spp.). Myriophyllum spicatum, frequently described as a nuisance organism, continues to become more common in Kansas, particularly in the western portion of the state.

Using trophic state data for macrophytes in the literature (Schneider and Melzer, 2003; Lehmann and LaChavanne, 1999; Sladecek, 1973), combined with abundance of aquatic plants in the lakes during 2003, 12 water bodies appeared to merit further assessment of the macrophyte community trophic classification. Five of these were assessed as eutrophic, two as very eutrophic, and five as on the cusp between eutrophic and very eutrophic. The trophic classification of six lakes were adjusted upwards based on the observed abundance and diversity of the macrophytic community (Table 2).

Table 4. Algal biovolumes calculated for the lakes surveyed during 2003. The "other" category refers to euglenoids, cryptophytes, dinoflagellates, and other single-celled flagellate forms of algae. Biovolume units are calculated in mm^3/L, and expressed as parts-per-million (ppm).

Lake	Biovolume (ppm)	Percent Composition			
		Green	Blue-Green	Diatom	Other
Augusta Santa Fe Lake	9.770	2	17	53	28
Banner Creek Lake	8.472	4	89	0	7
Butler Co. SFL	178.742	<1	88	11	<1
Cedar Bluff Lake	4.794	14	17	39	30
Chanute Santa Fe Lake	22.850	7	0	74	19
Chase Co. SFL	4.860	<3	71	<3	24
Cheyenne Bottoms	96.099	74	13	9	4
Clinton Lake	33.745	<1	25	7	68
Fort Scott Lake	5.113	9	68	5	18
Herington Reservoir	13.646	16	1	59	24
Hillsdale Lake (mean)	13.319	7	48	37	8
Hillsdale Lake Sta. 1	9.776	4	70	21	5
Hillsdale Lake Sta. 2	17.885	7	32	46	15
Hillsdale Lake Sta. 3	12.295	9	42	45	4
Jewell Co. SFL	7.315	25	31	7	37
Kanopolis Lake	12.760	15	23	14	48
Lake Kahola	5.073	21	3	13	63
Lake Shawnee	15.602	3	74	22	<1
Lone Star Lake	6.392	6	59	8	27
Miami Co. SFL	12.834	24	64	12	0
Milford Lake	9.161	16	81	3	<1
Mined Land Lake 6	269.771	0	91	<1	9
Mined Land Lake 7	1.068	9	55	<3	33
Mined Land Lake 12	0.561	40	13	25	22

Lake	Biovolume (ppm)	Percent Composition			
		Green	Blue-Green	Diatom	Other
Mined Land Lake 17	0.745	46	0	13	41
Mined Land Lake 27	1.551	6	80	0	14
Mined Land Lake 30	0.431	15	66	4	15
Ottawa Co. SFL	15.646	30	64	3	3
Perry Lake	9.579	10	6	69	15
Pleasanton Reservoir	30.337	25	19	39	17
Polk Daniels SFL	13.422	14	64	8	14
Pony Creek Lake	5.331	4	63	22	11
Quivera Big Salt Marsh	34.927	33	32	27	8
Quivera Little Salt Marsh	11.825	41	0	44	15
Shawnee Co. SFL	3.655	50	0	<1	50
Tuttle Creek Lake	2.836	9	33	0	58
Washington Co. SFL	13.714	7	21	30	42
Webster Lake	17.165	24	31	12	33
Wilson Lake	2.491	30	3	18	49

Table 5. Trends over time, based on a comparison to mean historic condition, for lake trophic state classification, for lakes surveyed during 2003.

Change in Trophic State Class Compared to Historic Mean	Number of Lakes	Percent Total
Improved Two Class Rankings	3	8.3
Improved One Class Ranking	8	22.2
Stable	17	47.2
Degraded One Class Ranking	6	16.7
Degraded Two Class Rankings	2	5.6
Total	36	100.0

Table 6. Macrophyte community structure in the 22 lakes surveyed for macrophytes during 2003. Macrophyte community refers only to the submersed and floating-leaved aquatic plants, not emergent shoreline plants. The percent areal cover is the abundance estimate for each documented species (Note: due to overlap in cover, the percentages under community composition may not equal the total cover).

Lake	% Total Cover	% Species Cover and Community Composition	
Augusta Santa Fe Lake	<5%		no species observed
Banner Creek Lake (limited survey)	30-50%	30-50%	*Potamogeton pectinatus*
Butler Co. SFL	7%	7%	*Najas guadalupensis* (sparse)
Chanute Santa Fe Lake	<7%		no species observed
Chase Co. SFL	<7%		no species observed
Fort Scott Lake (limited survey)	~20%	~20% ~20%	*Najas guadalupensis* *Potamogeton spp.*
Jewell Co. SFL	<7%		no species observed
Lake Kahola	<5%		no species observed
Lone Star Lake	40%	35% 35% 35% 20%	*Najas guadalupensis* *Potamogeton nodosus* *Potamogeton pectinatus* *Ceratophyllum demersum*
Miami Co. SFL	100%	100% 100% 100%	*Najas guadalupensis* *Nelumbo sp.* *Ceratophyllum demersum*
Mined Land Lake 6	40%	40%	*Najas guadalupensis* (sparse)
Mined Land Lake 7	100%	80% 60% 60% 33% 20% 7%	*Potamogeton pectinatus* *Chara vulgaris* *Najas guadalupensis* *Potamogeton illinoensis* *Myriophyllum spicatum* *Chara zeylanica*
Mined Land Lake 12	100%	100% 100% 100% 100%	*Chara zeylanica* *Myriophyllum spicatum* *Potamogeton nodosus* *Utrichularia gibba*
Mined Land Lake 17	100%	100% 100% 100% 100%	*Chara zeylanica* *Najas guadalupensis* *Potamogeton nodosus* *Potamogeton pectinatus*

Lake	% Total Cover	% Species Cover and Community Composition
Mined Land Lake 27	95%	95% *Ceratophyllum demersum* 50% *Myriophyllum spicatum* 15% *Chara globularis* 15% *Potamogeton illinoensis* 10% *Najas guadalupensis*
Mined Land Lake 30	100%	100% *Chara vulgaris* 67% *Najas guadalupensis* 20% *Chara zeylanica* 20% *Potamogeton pectinatus*
Ottawa Co. SFL	80%	80% *Ceratophyllum demersum* 80% *Lemna spp.* 80% *Myriophyllum spicatum* 80% *Najas guadalupensis* 80% *Nelumbo sp.* 80% *Potamogeton crispus* 80% *Potamogeton nodosus* 80% *Potamogeton pectinatus* 80% *Spirodela sp.*
Pleasanton Reservoir	<7%	<7% *Najas guadalupensis* (trace)
Polk Daniels SFL	<7%	no species observed
Pony Creek Lake	54%	47% *Najas guadalupensis* 47% *Potamogeton pectinatus* 33% *Potamogeton nodosus* 7% *Myriophyllum spicatum*
Shawnee Co. SFL	67%	67% *Potamogeton nodosus* 40% *Najas guadalupensis* 13% *Chara globularis*
Washington Co. SFL	73%	73% *Myriophyllum spicatum* 40% *Najas guadalupensis* 40% *Potamogeton foliosus* 7% *Potamogeton illinoensis*

Despite the seeming abundance of macrophytes within some lakes, as described by the frequency at which they are observed (Table 6), very few of these lakes have such biomass of aquatic plant material as to constitute a water quality related impairment. Only in the case of Ottawa Co. SFL would the volume of the water column having plant beds approach a concern. Even in this case, the macrophyte community did not appear to significantly influence or limit the algal community.

Only one lake appeared to have algal limitation due to macrophyte community influences, Mined Land Lake 12, and the percent of the water column with plant beds was not excessively high there. Overall, a larger impairment in Kansas Lakes is the lack of macrophyte habitat, rather than overabundance. In general, presence of a diverse macrophyte community reflects lower levels of human impact in our lakes.

Lake Stratification

Stratification is a natural process that may occur in any standing (lentic) body of water, whether that body is a natural lake, pond, artificial reservoir, or wetland pool (Wetzel, 1983). It occurs when sunlight (solar energy) penetrates into the water column. Due to the thermal properties of water, high levels of sunlight (combined with calm winds during the spring-to-summer months) cause layers of water to form with differing temperatures and densities. The cooler, denser layer (the hypolimnion) remains near the bottom of the lake while the upper layer (the epilimnion) develops a higher ambient temperature. The middle layer (the metalimnion) displays a marked drop in temperature with depth (the thermocline), compared to conditions within the epilimnion and hypolimnion. Once these layers of water with differing temperatures form, they tend to remain stable and do not easily mix with one another. This formation of distinct layers impedes, or precludes, the atmospheric reaeration of the hypolimnion, at least for the duration of the summer (or until ambient conditions force mixing). In many cases, this causes hypolimnetic waters to become depleted of oxygen and unavailable as habitat for fish and other forms of aquatic life. Stratification eventually breaks down in the fall when surface waters cool. Once epilimnetic waters cool to temperatures comparable to hypolimnetic waters, the lake will mix completely once again. Typically occurring in the fall, this phenomenon is called "lake turnover." Table 7 presents data related to thermal stratification in the 36 lakes surveyed in 2003, as well as calculated euphotic-to-mixed depth ratio.

Lake turnover can cause fishkills, aesthetic problems, and taste and odor problems in finished drinking water if the hypolimnion comprises a significant volume of the lake. This is because such a sudden mixing combines oxygen-poor, nutrient-rich hypolimnetic water with epilimnetic water lower in nutrients and richer in dissolved oxygen. Lake turnover can result in explosive algal growth, lowering of overall lake oxygen levels, and sudden fishkills. It also often imparts objectionable odors to the lake water and tastes and odors to finished drinking water produced from the lake. Thus, the stratification process is an important consideration in lake management.

The "enrichment" of hypolimnetic waters (with nutrients, metals, and other pollutants) during stratification results from the entrapment of materials that sink down from above, as well as materials that are released from lake sediments due to anoxic conditions. The proportion of each depends on the strength and duration of stratification, existing sediment quality, and inflow of materials from the watershed. For the majority of our larger lakes in Kansas, built on major rivers with dependable flow, stratification tends to be intermittent (polymictic), or missing, and the volume of the hypolimnion tends to be small in proportion to total lake volume. These conditions tend to lessen the importance of sediment re-release of pollutants in the largest Kansas lakes, leaving watershed pollutant inputs as the primary cause of water quality problems.

Table 7. Stratification status of the 36 water bodies surveyed during 2003. The term "n.a." indicates that boat access, wind conditions, shallowness, or equipment problems prevented the collection of profile data or made said collection superfluous.

Lake	Date Sampled (M-D-Yr)	Temperature Decline Rate (degree C/meter)	Dissolved Oxygen Decline Rate (mg/L/meter)	Thermocline Depth (meters)	Maximum Lake Depth (meters)	Euphotic/Mixed Depth Ratio*
Augusta Santa Fe Lake	08-18-2003	0.40	0.48	none	2.5	1.85
Banner Creek Lake	06-17-2003	1.00	0.93	3.0-5.0	10.0	1.15
Butler Co. SFL	08-18-2003	0.50	2.85	none	4.0	0.54
Cedar Bluff Lake	08-04-2003	0.50	0.43	9.0-15.0	18.0	0.66
Chanute Santa Fe Lake	07-07-2003	1.81	0.73	3.0-4.0	9.0	0.70
Chase Co. SFL	08-19-2003	1.09	0.64	6.0-8.0	11.0	1.05
Cheyenne Bottoms	06-09-2003	n.a.	n.a.	none	1.0	33.74
Clinton Lake	07-15-2003	0.55	0.77	6.0-8.0	11.0	0.64
Fort Scott Lake	07-08-2003	1.05	0.68	5.0-7.0	11.0	1.17
Herington Reservoir	07-28-2003	0.08	0.68	none	7.0	0.86
Hillsdale Lake Sta. 1	07-16-2003	0.64	0.68	5.0-7.0	12.0	0.71
Hillsdale Lake Sta. 2	07-16-2003	0.50	1.23	5.0-7.0	7.5	0.86
Hillsdale Lake Sta. 3	07-16-2003	0.33	1.02	5.0-6.5	6.5	1.11
Jewell Co. SFL	06-23-2003	0.25	0.50	none	4.0	0.83
Kanopolis Lake	07-21-2003	0.19	0.44	none	9.0	0.74
Lake Kahola	07-28-2003	0.89	0.68	6.0-8.0	10.0	0.97
Lake Shawnee	06-30-2003	0.85	0.58	5.0-7.0	13.0	0.76

Lake	Date Sampled (M-D-Yr)	Temperature Decline Rate (degree C/meter)	Dissolved Oxygen Decline Rate (mg/L/meter)	Thermocline Depth (meters)	Maximum Lake Depth (meters)	Euphotic/Mixed Depth Ratio*
Lone Star Lake	08-11-2003	0.79	1.06	4.0-6.0	8.0	1.03
Miami Co. SFL	06-16-2003	n.a.	n.a.	none	2.0	12.09
Milford Lake	07-21-2003	0.29	0.48	8.0-13.0	18.0	0.61
Mined Land Lake 6	08-26-2003	n.a.	n.a.	unknown	3.5	0.40
Mined Land Lake 7	08-26-2003	1.33	1.12	4.0-6.0	10.0	0.98
Mined Land Lake 12	07-07-2003	2.33	1.00	4.0-6.0	6.0	1.51
Mined Land Lake 17	08-25-2003	1.50	0.36	5.0-8.0	14.0	0.79
Mined Land Lake 27	08-25-2003	2.00	0.92	4.0-7.0	10.0	0.93
Mined Land Lake 30	08-25-2003	1.81	0.12	6.0-8.0	14.0	0.85
Ottawa Co. SFL	06-23-2003	0.00	1.07	none	3.0	2.93
Perry Lake	07-15-2003	0.40	0.59	6.0-8.0	10.0	0.80
Pleasanton Reservoir	08-11-2003	1.38	0.85	3.0-6.0	8.0	0.98
Polk Daniels SFL	08-18-2003	1.33	1.30	1.0-3.0	6.0	1.16
Pony Creek Lake	06-17-2003	1.20	1.11	2.0-4.0	11.0	1.13
Quivera Big Salt Marsh	06-10-2003	n.a.	n.a.	none	1.0	82.78
Quivera Little Salt Marsh	06-10-2003	n.a.	n.a.	none	1.0	6.71
Shawnee Co. SFL	06-30-2003	1.13	0.98	3.0-5.0	9.0	1.15
Tuttle Creek Lake	08-05-2003	0.22	0.32	none	18.0	0.50

Lake	Date Sampled (M-D-Yr)	Temperature Decline Rate (degree C/meter)	Dissolved Oxygen Decline Rate (mg/L/meter)	Thermocline Depth (meters)	Maximum Lake Depth (meters)	Euphotic/Mixed Depth Ratio*
Washington Co. SFL	09-03-2003	0.30	1.76	none	5.0	1.38
Webster Lake	08-04-2003	0.21	0.87	none	7.5	0.60
Wilson Lake	07-21-2003	0.31	0.34	11.0-18.0	21.0	0.70

* = Ratios greater than unity suggest either clearer lakes or very shallow and well mixed water bodies. Ratios much less than 0.7 indicate lakes with inorganic turbidity, self shaded conditions due to abundant phytoplankton, or deep lakes with lower turbidity. When used with other metrics, this ratio can add greatly to an overall understanding of a lake's physical ecology. For a further explanation of euphotic depth, refer to the discussion on page 21.

Presence or absence of stratification is determined by the depth profiles taken in each lake for temperature and dissolved oxygen concentration. Table 7 presents these data. Temperature decline rates (for the entire water column) greater than 1.0°C/m are considered evidence of stronger thermal stratification, although temperature changes may be less pronounced during the initiation phase of stratification. Lakes with strong thermal stratification will be more resistant to mixing of the entire water column pending the cooling of epilimnetic waters in autumn.

The temperature decline rate, however, must also be considered in relation to the particular lake and the shape of the temperature-to-depth relationship. The sharper the discontinuity in the data plot, the stronger the level of thermal stratification. Gradual declines in temperature with depth, through the entire water column, and indistinct discontinuities in data plots are more indicative of weaker thermal stratification. The strength of the oxycline, based on water column decline rate and the shape of the data plot, is also used to estimate stratification in lakes. A strong oxycline might be seen by mid-summer in lakes with weak thermal stratification if the lakes are not prone to wind mixing, or in the case of dense macrophyte beds.

Euphotic depth, or the depth to which light sufficient for photosynthesis penetrates, can be calculated from relationships derived from Secchi depth and chlorophyll-a data (Scheffer, 1998). This report presents the ratio of calculated euphotic depth to calculated mixing depth, which is the depth to which wind circulation and stratification should reach typically. The metric supplies a means to interpret light and production relationships in a lake, provided other factors, such as depth and thermal stratification, are also considered simultaneously. For instance, a very high ratio may mean a lake is exceptionally clear, or may mean it is very shallow and well mixed. Examples of the former include Mined Land Lake 12. Examples of the latter case include Cheyenne Bottoms. A very low value likely means the lake is light limited due to inorganic turbidity (as in the case of Tuttle Creek Lake) or self-shaded due to large algal biomass near the surface (as in the case of Butler Co. SFL).

Fecal Coliform Bacteria

Since 1996, bacterial sampling has taken place at the primary water quality sampling station at each lake. While many Kansas lakes have swimming beaches, many do not. However, presence or absence of a swimming beach does not determine whether or not a lake supports primary contact recreational use. Primary contact recreation is defined as, "recreation during which the body is immersed in surface water to the extent that some inadvertent ingestion of water is probable" (KDHE, 2003), which includes swimming, water skiing, wind surfing, jet skiing, diving, boating, and other similar activities. The majority of Kansas lakes have some form of primary contact recreation taking place during the warmer half of the year. Sampling of swimming beaches is also often conducted by lake managers to document water quality where people are concentrated in a small area. These managers are in the best position to collect samples frequently enough to determine compliance with the regulations at these swimming beaches (KDHE, 2003).

Given the rapid die-off of fecal coliform bacteria in the aquatic environment, due to protozoan predation and a generally hostile set of environmental conditions, high fecal coliform bacterial counts should only occur in the open water of a lake if there has been 1) a recent pollution event, or 2) a chronic input of bacteria-laced pollution. A single set of bacterial samples collected from the open, deep water, environment is normally considered representative of whole-lake bacterial water quality at the time of the survey. This environment is also less prone to short lived fluctuations in bacterial counts than are swimming beaches and other shoreline areas.

Table 8 presents the bacterial data collected during the 2003 sampling season. Nine lakes, out of the 36 lakes surveyed for fecal coliform bacteria, had fecal coliform bacterial counts greater than the analytical reporting limit. Although no lake in 2003 exceeded existing criteria (KDHE, 2003) as a geometric mean, two lakes had suspiciously high and unexpected fecal coliform counts. These two lakes are Chase Co. SFL and Mined Land Lake 6 (which also experienced elevated nutrients and chlorophyll-a). Two others had moderate bacteria counts, Pleasanton Reservoir and Jewell Co. SFL, believed exacerbated by windy conditions and mixing at the time of survey.

Chase Co. SFL is in a fairly unimpacted watershed which would not be expected to have high fecal bacterial counts. However, manure was being applied to land near the lake at the time of the survey, using large spreading cannons that shoot manure/lagoon effluent into the air. This may well have provided bacterial contamination to the lake via aerial deposition. Mined Land Lake 6 would also not be expected to have high fecal bacteria counts given its drainage conditions. However, this small lake has experienced elevated nutrient levels, and now higher bacterial counts, since recent infrastructure renovations. The potential exists that a renovated nearby latrine may be seeping wastewater.

Table 8. Fecal coliform bacterial counts (mean of duplicate samples) from the 36 lakes surveyed for fecal coliform bacteria during 2003. Note: These samples were collected during the week, not during weekends, when recreational activity would be at peak levels. All units are in "number of cfu/100 mL of lake water."

Lake	Site Location	Fecal Coliform Count
Augusta Santa Fe Lake	open water	<10
Banner Creek Lake	open water	<10
Butler Co. SFL	open water	35
Cedar Bluff Lake	open water	<10
Chanute Santa Fe Lake	open water	40
Chase Co. SFL	open water	320
Cheyenne Bottoms	shoreline	10
Clinton Lake	open water	<10

Lake	Site Location	Fecal Coliform Count
Fort Scott Lake	open water	<10
Herington Reservoir	open water	<10
Hillsdale Lake	open water	<10
Jewell Co. SFL	open water	135
Kanopolis Lake	open water	<10
Lake Kahola	open water	<10
Lake Shawnee	open water	<10
Lone Star Lake	open water	<10
Miami Co. SFL	off of dock	15
Milford Lake	open water	<10
Mined Land Lake 6	shoreline	295
Mined Land Lake 7	open water	<20
Mined Land Lake 12	open water	<10
Mined Land Lake 17	open water	<10
Mined Land Lake 27	open water	<10
Mined Land Lake 30	open water	<10
Ottawa Co. SFL	open water	<20
Perry Lake	open water	<10
Pleasanton Reservoir	open water	120
Polk Daniels SFL	open water	<10
Pony Creek Lake	open water	<10
Quivera Big Salt Marsh	shoreline	<10
Quivera Little Salt Marsh	shoreline	30
Shawnee Co. SFL	open water	<10
Tuttle Creek Lake	open water	<10
Washington Co. SFL	open water	<10
Webster Lake	open water	<10
Wilson Lake	open water	<10

Limiting Nutrients and Physical Parameters

The determination of which nutrient, or physical characteristic, "limits" phytoplankton production is of primary importance in lake management. If certain features can be shown to exert exceptional influence on lake water quality, those features can be addressed in lake protection plans to a greater degree than less important factors. In this way, lake management can be made more efficient.

Common factors that limit algal production in lakes are the level of available nutrients (phosphorus and nitrogen, primarily), and the amount of light available in the water column for photosynthesis. Less common limiting factors in lakes, and other lentic waterbodies, include available levels of carbon, iron, and certain trace elements (such as molybdenum or vitamins), as well as grazing pressure on the phytoplankton community, competition from macrophytes and/or periphyton, water temperature, and hydrologic flushing rate.

Nutrient ratios are commonly considered in determining which major plant nutrients are limiting factors in lakes. These ratios take into account the relative needs of algae for the different chemical elements versus availability in the environment. Typically, total nitrogen/total phosphorus (TN/TP) mass ratios above 10-12 indicate increasing phosphorus limitation. Conversely, TN/TP ratios of less than 7-10 indicate increasing importance of nitrogen. Ratios of 7-to-12 indicate that both nutrients, or neither, may limit algal production (Wetzel, 1983; Horne and Goldman, 1994). It should also be kept in mind, when determining limiting factors, that highly turbid lakes typically have lower nutrient ratios, but may still have phosphorus limitation due to availability (e.g., adsorption to particles) issues (Jones and Knowlton, 1993).

Table 9 presents limiting factor determinations for the lakes surveyed during 2003. These determinations reflect the time of sampling (chosen to reflect average conditions during the summer growing season to the extent possible) but may be less applicable to other times of the year. Conditions during one survey may also differ significantly from conditions during past surveys, despite efforts to sample during times representative of "normal" summer conditions. If such a situation is suspected, it is noted in Table 9 or elsewhere in the report.

As indicated in Table 9, phosphorus was the primary limiting factor identified for lakes surveyed in 2003. Fifteen of the 36 lakes (42%) were determined to be primarily limited by phosphorus. Ten lakes (28%) were determined to be primarily nitrogen limited. One lake was primarily light limited (<3%). Another six lakes (17%) were co-limited by phosphorus and nitrogen or limited by combinations of nutrients and/or light availability. Two lakes (6%) were primarily limited by availability of iron or other micronutrients. Algal production in one lake (<3%) was determined to be limited by a combination of iron and interactions with the macrophyte community. One lake (<3%) was determined to be primarily limited by hydrologic conditions. Mean TN/TP ratio was 19.9 for the lakes in 2003 (median = 17.0).

Table 9. Limiting factor determinations for the 36 lakes surveyed during 2003. NAT = non-algal turbidity, TN/TP = nitrogen-to-phosphorus ratio, Z_{mix} = depth of mixed layer, Chl-a = chlorophyll-a, and SD = Secchi depth. N = nitrogen, P = phosphorus, C = carbon, Fe = iron, and L = light. Shading = calculated light attenuation coefficient times mean lake depth.

Lake	TN/TP	NAT	Z_{mix}*NAT	Chl-a*SD	Chl-a/TP	Z_{mix}/SD	Shading	Factors
Augusta Santa Fe Lake	7.8	2.008	2.360	6.26	0.115	2.798	2.69	N
Banner Creek Lake	27.7	0.273	0.935	18.20	0.379	1.715	4.09	P
Butler Co. SFL	16.4	<0.010	<0.010	78.28	1.018	3.879	8.42	P>N
Cedar Bluff Lake	31.8	0.231	1.425	18.92	0.307	2.705	9.38	P
Chanute Santa Fe Lake	7.7	1.002	3.219	16.76	0.251	5.542	6.61	N>L
Chase Co. SFL	24.0	0.477	1.732	10.79	0.307	2.371	4.51	P
Cheyenne Bottoms	17.5	4.015	0.100	15.91	0.444	0.165	0.75	P>N
Clinton Lake	10.0	0.022	0.093	38.98	0.420	3.622	7.74	N≥P
Fort Scott Lake	16.1	0.326	1.182	11.33	0.224	1.649	4.06	P=N
Herington Reservoir	13.0	0.702	2.257	16.68	0.261	3.873	5.39	P=N
Hillsdale Lake (whole lake)	19.1	0.449	2.134	20.12	0.562	4.295	8.00	P>N
Hillsdale Lake Station 1	24.8	0.483	2.294	16.06	0.480	3.833	7.32	P
Hillsdale Lake Station 2	16.6	0.433	1.386	23.56	0.605	3.372	5.39	P>N
Hillsdale Lake Station 3	17.4	0.465	1.310	18.98	0.579	2.493	4.12	P>N
Jewell Co. SFL	12.8	1.266	3.045	16.19	0.310	5.116	5.51	(P=N)>L
Kanopolis Lake	14.2	0.858	3.342	12.19	0.243	4.806	6.51	(P=N)>L
Lake Kahola	18.4	0.627	2.151	12.15	0.304	3.091	4.83	P>N

Lake	TN/TP	NAT	Z_{mix}*NAT	Chl-a*SD	Chl-a/TP	Z_{mix}/SD	Shading	Factors
Lake Shawnee	18.4	<0.010	<0.010	42.84	0.611	2.472	6.49	P>N
Lone Star Lake	26.4	0.344	1.310	14.82	0.245	2.081	4.66	P
Miami Co. SFL	14.6	0.303	0.087	21.83	0.152	0.191	0.65	N>P
Milford Lake	6.3	0.151	0.878	28.86	0.130	3.151	9.63	N
Mined Land Lake 6	23.3	<0.010	<0.010	65.46	1.593	6.703	11.58	P
Mined Land Lake 7	28.8	0.258	1.237	7.16	0.225	1.506	5.28	Micronutrients ≥P
Mined Land Lake 12	12.5	0.237	0.776	3.47	0.090	0.849	3.09	Macrophytes ≥Fe
Mined Land Lake 17	15.0	0.173	1.080	9.32	0.124	1.408	7.98	N≥P
Mined Land Lake 27	47.8	0.184	0.936	12.77	0.345	1.375	5.79	P
Mined Land Lake 30	27.2	0.200	1.168	5.78	0.135	1.366	6.94	Micronutrients ≥P
Ottawa Co. SFL	11.4	0.371	0.334	26.36	0.243	0.979	1.81	N>P
Perry Lake	9.9	0.437	1.960	15.19	0.255	3.160	6.34	N>P
Pleasanton Reservoir	15.1	0.048	0.130	37.86	0.545	2.417	4.68	P=N
Polk Daniels SFL	22.0	0.330	0.894	23.62	0.476	2.183	3.95	P
Pony Creek Lake	55.6	0.519	1.668	11.76	0.270	2.363	4.12	P
Quivera Big Salt Marsh	20.0	1.808	0.045	9.62	0.216	0.059	0.30	N=P
Quivera Little Salt Marsh	20.2	2.521	0.721	5.71	0.108	0.841	1.16	Flow > Other Factors
Shawnee Co. SFL	8.4	0.516	1.657	11.13	0.234	2.296	4.05	N
Tuttle Creek Lake	8.7	1.117	6.892	5.58	0.028	8.009	12.48	L

Lake	TN/TP	NAT	Z_{mix}*NAT	Chl-a*SD	Chl-a/TP	Z_{mix}/SD	Shading	Factors
Washington Co. SFL	8.2	0.241	0.540	27.54	0.257	1.735	3.31	N
Webster Lake	18.9	0.636	2.854	18.88	0.295	5.406	8.39	P>N
Wilson Lake	60.1	0.419	2.445	8.97	0.485	3.151	8.36	P

Criteria Table

Expected Lake Condition	TN/TP	NAT	Z_{mix}*NAT	Chl-a*SD	Chl-a/TP	Z_{mix}/SD	Shading
Phosphorus Limiting	>12				>0.40		
Nitrogen Limiting	<7				<0.13		
Light/Flushing Limited		>1.0	>6	<6	<0.13	>6	>16
High Algae-to-Nutrient Response		<0.4	<3	>16	>0.40	<3	
Low Algae-to-Nutrient Response		>1.0	>6	<6	<0.13	>6	
High Inorganic Turbidity		>1.0	>6	<6		>6	>16
Low Inorganic Turbidity		<0.4	<3	>16		<3	<16
High Light Availability			<3	>16		<3	<16
Low Light Availability			>6	<6		>6	>16

Two water bodies may have shown some interference due to recent rainfall, and thus deviation to some degree from average summer condition. Quivera Little Salt Marsh may have had higher flushing than normal during its June survey. The water level in Chanute Santa Fe Lake was approximately 0.3 meters above normal at the time of its survey with water quality somewhat atypical of past surveys. Typically, a lake will return to its pre-rainfall quality fairly rapidly after the passage of a storm front, usually within a week or less. However, Chanute Santa Fe Lake seemed to have lingering water quality impacts two weeks after the runoff event.

In addition to nutrient ratios, the following six metrics are applied in determining the relative roles of light and nutrient limitation for lakes in Kansas (c.f., Walker, 1986; Scheffer, 1998).

1) Non-Algal Turbidity = $(1/SD)-(0.025m^2/mg*C)$,

where SD = Secchi depth in meters and C = chlorophyll-a in mg/m^3.

Non-algal turbidity values $<0.4\ m^{-1}$ tend to indicate very low levels of suspended silt and/or clay, while values $>1.0\ m^{-1}$ indicate that inorganic particles are important in creating turbidity. Values between 0.4 and $1.0\ m^{-1}$ describe a range where inorganic turbidity assumes greater influence on water clarity as the value increases, but would not assume a significant limiting role until values exceed $1.0\ m^{-1}$.

2) Light Availability in the Mixed Layer = Z_{mix}*Non-Algal Turbidity,

where Z_{mix} = depth of the mixed layer, in meters.

Values <3 indicate abundant light within the mixed layer of a lake and a high potential response by algae to nutrient inputs. Values >6 indicate the opposite.

3) Partitioning of Light Extinction Between Algae and Non-Algal Turbidity = Chl-a*SD,

where Chl-a = chlorophyll-a in mg/m^3 and SD = Secchi depth in meters.

Values <6 indicate that inorganic turbidity is primarily responsible for light extinction in the water column and there is a weak algal response to changes in nutrient levels. Values >16 indicate the opposite.

4) Algal Use of Phosphorus Supply = Chl-a/TP,

where Chl-a = chlorophyll-a in mg/m^3 and TP = total phosphorus in mg/m^3 .

Values <0.13 indicate a limited response by algae to phosphorus; i.e., nitrogen, light, or other factors may be more important. Values above 0.4 indicate a strong algal response to changes in phosphorus level. The range 0.13-to-0.4 suggests a variable but moderate response by algae to phosphorus levels.

5) Light Availability in the Mixed Layer for a Given Surface Light = Z_{mix}/SD,

where Z_{mix} = depth of the mixed layer, in meters, and SD = Secchi depth in meters.

Values <3 indicate that light availability is high in the mixed zone and the probability of strong algal responses to changes in nutrient levels is high. Values >6 indicate the opposite.

6) Shading in Water Column due to Algae and Inorganic Turbidity = $Z_{mean}*E$,

where Z_{mean} = mean lake depth, in meters, and E = calculated light attenuation coefficient, in units of m^{-1}, derived from Secchi depth and chlorophyll-a data (Scheffer, 1998).

Values >16 indicate high levels of self-shading due to algae or inorganic turbidity in the water column. Values <16 indicate that self-shading of algae does not significantly impede productivity. The metric is most applicable to lakes with maximum depths of less than 5 meters (Scheffer, 1998).

In addition to the preceding metrics, an approach developed by Carlson (1991) was employed to test the limiting factor determinations made from the suite of metrics utilized in this, and previous, reports. The approach uses the Carlson trophic state indices for total phosphorus, chlorophyll-a, Secchi depth, and the newer index for total nitrogen. Index scores are calculated for each lake, then metrics are calculated for $TSI_{(Secchi)}$-$TSI_{(Chl-a)}$ and for $TSI_{(TP\ or\ TN)}$-$TSI_{(Chl-a)}$. The degree of deviation of each of these metrics from zero provides a measure of the potential limiting factors. In the case of the metric dealing with Secchi depth and chlorophyll, a positive difference indicates small particle turbidity is important, while a negative difference indicates that larger particles (zooplankton, algal colonies) exert more importance for a lake's light regime. In the case of the metric dealing with nutrients, a positive difference indicates the nutrient in question may not be the limiting factor, while a negative difference strengthens the assumption that the particular nutrient limits algal production and biomass. Differences of more than 5 units were used as the threshold for determining if the deviations were significantly different from zero. This approach generally produced the same determinations as those derived from the original suite of metrics. It clearly identified those lakes with extreme turbidity or those with algal colonies or large celled algal species. However, the $TSI_{(TN)}$ scores are given less weight than the other TSI calculations because the metric was developed using water quality data from Florida lakes which may render it less representative for our region.

In identifying the limiting factors for lakes, primary attention was given to the metrics calculated from 2003 data. However, past Secchi depth and chlorophyll-a data were also considered for comparative purposes. Additionally, mean and maximum lake depth were taken into account when ascribing the importance of non-algal turbidity. Lakes with fairly high non-algal turbidity may have little real impact from that turbidity if the entire water column rapidly circulates (Scheffer, 1998).

Surface Water Exceedences of State Water Quality Criteria

Most numeric and narrative water quality criteria referred to in this section are taken from the Kansas Administrative Regulations (K.A.R. 28-16-28b through K.A.R. 28-16-28f), or from EPA water quality criteria guidance documents (EPA, 1972, 1976; KDHE, 2003) for ambient waters and finished drinking water. Copies of the Standards may be obtained from the Bureau of Water, KDHE, 1000 Southwest Jackson Ave., Suite 420, Topeka, Kansas 66612.

Tables 11, 12, and 13 present documented exceedences of surface water quality criteria and goals during the 2003 sampling season. These data were generated by computerized comparison of the 2003 Lake and Wetland Monitoring Program data to the state surface water quality standards and other federal guidelines. Only those samples collected from a depth of ≤3.0 meters were used to document standards violations, as a majority of those samples collected from below 3.0 meters were from hypolimnetic waters. In Kansas, lake hypolimnions generally constitute a small percentage of total lake volume and, while usually having more pollutants present in measurable quantities, compared to overlying waters, do not generally pose a significant water quality problem for the lake as a whole.

Criteria for eutrophication and turbidity in the Kansas standards are narrative rather than numeric. However, lake trophic state does exert a documented impact on various lake uses, as does inorganic turbidity. The system on the following page (Table 10) has been developed over the last ten years to define how lake trophic status influences the various designated uses of Kansas lakes (EPA, 1990; NALMS, 1992). Trophic state/use support expectations are compared with the observed trophic state conditions to determine the level of use support at each lake. The report appendix from the 2002 annual program report presents a comparison of these trophic class based assessments, as well as turbidity based assessments, versus risk based values (KDHE, 2002). In general, the risk based thresholds compare fairly well with the assessment system presently in use.

With respect to the aquatic life support use, eutrophication, high pH, and low dissolved oxygen within the upper 3.0 meters comprised the primary water quality concerns during 2003 (Table 11). Thirteen lakes exhibited trophic states high enough to impair long or short term aquatic life support. Five lakes had low dissolved oxygen conditions within the top 3.0 meters of the water column. Two lakes had pH levels high enough to impact aquatic life support. One lake exhibited chronic turbidity sufficient to impact long term community structure and function.

Eutrophication exceedences are primarily due to excessive nutrient inputs from lake watersheds. Dissolved oxygen problems are generally due to advanced trophic state, which causes rapid oxygen depletion below the thermocline, but are also observed in lakes that do not exhibit excessive trophic state conditions. In these cases, the low dissolved oxygen levels likely result from shallow stratification conditions. Lakes with elevated pH are also reflective of high trophic state and algal or macrophytic production.

Table 10. Lake use support determination based on lake trophic state.

Designated Use	A	M	SE	E	VE	H-no BG TSI 64-70	H-no BG TSI 70+	H-with BG TSI 64+
Aquatic Life Support	X	Full	Full	Full	Partial	Partial	Non	Non
Drinking Water Supply	X	Full	Full	Partial	Partial	Non	Non	Non
Primary Contact Recreation	X	Full	Full	Partial	Partial	Non	Non	Non
Secondary Contact Recreation	X	Full	Full	Full	Partial	Partial	Non	Non
Livestock Water Supply	X	Full	Full	Full	Partial	Partial	Non	Non
Irrigation	X	Full	Full	Full	Partial	Partial	Non	Non
Groundwater Recharge	Trophic state is not generally applicable to this use.							
Food Procurement	Trophic state is applicable to this use, but not directly.							

BG = blue-green algae dominate the community (50%+ as cell count and/or 33%+ as biovolume)
X = use support assessment based on nutrient load and water clarity, not algal biomass

A = argillotrophic (high turbidity lake)
M = mesotrophic (includes OM, oligo-mesotrophic, class), TSI = zero-to-49.9
SE = slightly eutrophic, TSI = 50-to-54.9
E = eutrophic (fully eutrophic), TSI = 55-to-59.9
VE = very eutrophic, TSI = 60-to-63.9
H = hypereutrophic, TSI $\geq$ 64

TSI = 64 = chlorophyll-a of 30 ug/L
TSI = 70 = chlorophyll-a of 56 ug/L

During 2003, the fourth consecutive year of exceptionally dry and hot summer conditions, many lakes continued to show clearer water columns than observed in past times. The extended dry conditions, which have led to greatly reduced runoff and inflows at many lakes and subsequent drops in water level at some, have also resulted in reductions in the magnitude and frequency of water quality standards exceedences related to pesticides and heavy metals. In other cases, however, lower water levels have allowed resuspension of sediments, bringing silt and associated pollutants into water columns. For lakes typically limited by nutrient inputs, the net result has been to improve overall water quality except for those lakes with water levels lowered to the degree that resuspension exerts impacts. For lakes that are typically light limited the effect has often been to trade inorganic turbidity for increased algal biomass, trading one water quality impact for another. However, in light limited lakes where wind resuspension or bottom feeding fish communities create turbid conditions, the effects of reduced allochthonous inputs are not generally discernable.

There were 36 exceedences of water supply criteria and/or guidelines during 2003 (Table 12). The majority were for eutrophication related conditions (58%). Of these 36 exceedences, only nine (25%) occurred in lakes that currently serve as public water supplies. Irrigation use criteria were exceeded in 13 lakes, one of which currently is designated for irrigation supply. The other 12 lakes are pending use attainability analyses for irrigation use. Livestock watering criteria were exceeded in 16 lakes, all of which are pending use attainability analyses for that use. Human health (food procurement use) criteria for mercury were exceeded in one lake.

Table 13 lists 22 lakes with trophic state/turbidity conditions high enough to impair contact recreational uses. Thirteen of the lakes surveyed had high enough trophic state or turbidity to impair secondary contact recreation during 2003.

In all, there were 148 exceedences of numeric or narrative criteria, water quality goals, or EPA guidelines documented in Kansas lakes during 2003. This represents a considerable drop from last year (34% less), which can be largely attributed to continuing low rainfall and runoff. Approximately 30.4% of these exceedences related to aquatic life support, 44.6% related to consumptive uses, and 25.0% related to recreational uses. A total of 61% occurred in lakes designated for the indicated uses, while 39% occurred in lakes where uses have not yet been verified through use attainability analyses. Eutrophication, turbidity, high pH, or low dissolved oxygen accounted for 83% of documented water quality impacts in 2003. Only 2% of the impacts were linked to heavy metals and metalloids. There were no pesticide related water quality exceedences in 2003, although detections of acetochlor (a replacement herbicide for atrazine) continue to increase in both frequency and magnitude. As stated last year, this may represent a future water quality concern.

Table 11. Chemical and biological parameters not complying with chronic and acute aquatic life support (ALS) criteria in lakes surveyed during 2003. DO = dissolved oxygen, EN = eutrophication or high nutrient load, and TN = high turbidity and nutrient load. Only those lakes with some documented water quality problem are included in Tables 11, 12, and 13.

	Chronic ALS						Acute ALS			
Lake	EN*	TN*	pH*	DO*	Hg	Se	EN*	pH*	DO*	Cl
Banner Creek Lake					X					
Butler Co. SFL	X		X	X			X	X	X	
Chanute Santa Fe Lake	X			X			X		X	
Cheyenne Bottoms	X					X	X			
Clinton Lake	X						X			
Herington Reservoir	X						X			
Jewell Co. SFL	X						X			
Kanopolis Lake				X					X	
Lake Shawnee	X						X			
Mined Land Lake 6	X						X			
Ottawa Co. SFL	X						X			
Pleasanton Reservoir	X			X			X		X	
Polk Daniels SFL				X					X	
Quivera Big Salt Marsh	X		X				X	X		X
Quivera Little Salt Marsh										X
Tuttle Creek Lake		X								

	Chronic ALS						Acute ALS			
	EN*	TN*	pH*	DO*	Hg	Se	EN*	pH*	DO*	Cl
Washington Co. SFL	X						X			
Webster Lake	X						X			

* = Although there are no specific chronic versus acute criteria for these parameters, the magnitude of the excursions are used to determine whether the impact is of immediate or long term importance. Measured values for dissolved oxygen and pH can be dependent on when samples are collected during a 24 hour cycle. When nutrient pollution and eutrophication are high, one can assume higher pH and lower dissolved oxygen conditions occur at some point during this 24 hour cycle.

Table 12. Exceedence of human use criteria and/or EPA guidelines within the water column of lakes surveyed during 2003. EN = high trophic state or nutrient loads. Only lakes with documented exceedences are included within the table. An "X" indicates that the exceedence occurred for a presently designated use. An "(X)" indicates that the exceedence occurred where the indicated use has not yet been verified by use attainability analyses.

	Water Supply			Irrigation	Livestock Water		Human Health (i.e., Food Procurement)
Lake	EN	Cl	SO_4	EN	EN	SO_4	Hg
Augusta Santa Fe Lake	X						
Banner Creek Lake							X
Butler Co. SFL	(X)			(X)	(X)		
Cedar Bluff Lake			(X)				
Chanute Santa Fe Lake	(X)			(X)	(X)		
Cheyenne Bottoms	(X)	(X)	(X)	(X)	(X)		
Clinton Lake	X			(X)	(X)		
Herington Reservoir	X			(X)	(X)		
Hillsdale Lake	X						
Jewell Co. SFL	(X)			(X)	(X)		
Kanopolis Lake	X						
Lake Shawnee	(X)			(X)	(X)		
Miami Co. SFL	(X)						
Milford Lake	X						
Mined Land Lake 6	(X)			(X)	(X)		

	Water Supply			Irrigation	Livestock Water		Human Health (i.e., Food Procurement)
Lake	EN	Cl	SO_4	EN	EN	SO_4	As
Mined Land Lake 7			(X)			(X)	
Mined Land Lake 12			(X)				
Mined Land Lake 17			(X)			(X)	
Mined Land Lake 27			(X)				
Mined Land Lake 30			(X)			(X)	
Ottawa Co. SFL	(X)	(X)	(X)	(X)	(X)		
Pleasanton Reservoir	X			(X)	(X)		
Polk Daniels SFL	X						
Quivera Big Salt Marsh	(X)	(X)		(X)	(X)		
Quivera Little Salt Marsh	(X)	(X)					
Tuttle Creek Lake	X						
Washington Co. SFL	(X)			(X)	(X)		
Webster Lake	(X)		(X)	X	(X)		
Wilson Lake		(X)	(X)				

Table 13. Exceedences of numeric and narrative recreational guidelines for lakes surveyed during 2003. Primary contact recreation refers to recreation where ingestion of lake water is likely. Secondary contact recreation involves a low likelihood of accidental ingestion of lake water. EN = high trophic state and nutrient loads and TN = high turbidity and nutrient loads. FC = fecal coliform count. An "X" indicates that a use attainability study has been completed and/or the use was previously designated for that lake. An "(X)" indicates that the use has not been verified through a formal use attainability analysis. Only lakes with impairments are listed.

	Primary Contact Recreation			Secondary Contact Recreation	
Lake	**EN**	**TN**	**FC***	**EN**	**TN**
Augusta Santa Fe Lake	X				
Butler Co. SFL	X			X	
Chanute Santa Fe Lake	X			X	
Chase Co. SFL			X		
Cheyenne Bottoms	(X)			X	
Clinton Lake	X			X	
Herington Reservoir	X			X	
Hillsdale Lake	X				
Jewell Co. SFL	X			X	
Kanopolis Lake	X				
Lake Shawnee	X			X	
Miami Co. SFL	X				
Milford Lake	X				
Mined Land Lake 6	X		X	X	
Ottawa Co. SFL	X			X	
Pleasanton Reservoir	X			X	
Polk Daniels SFL	X				
Quivera Big Salt Marsh	(X)			X	
Quivera Little Salt Marsh	(X)				
Tuttle Creek Lake	X	X			

Lake	Primary Contact Recreation			Secondary Contact Recreation	
	EN	TN	FC*	EN	TN
Washington Co. SFL	X			X	
Webster Lake	X			X	

* = For a strict comparison to recreational water quality standards, fecal coliform data must be collected on five separate days during a 30 day period. However, two lakes had unusually high counts in their open water zone at the time of their surveys. Such counts from the open water do constitute a water quality impact that should be considered in any overall assessment of these water bodies.

Pesticides in Kansas Lakes, 2003

Detectable levels of at least one pesticide were documented in the main body of 19 lakes sampled in 2003 (53% of lakes surveyed for pesticides). Table 14 lists these lakes and the pesticides that were detected, along with the level measured and the analytical quantification limit. Five different pesticides, and one pesticide degradation byproduct, were noted in 2003. Of these five compounds, atrazine and alachlor currently have numeric criteria in place for aquatic life support and/or water supply uses (KDHE, 2003).

Atrazine continues to be the pesticide detected most often in Kansas lakes (KDHE, 1991). Atrazine, and the atrazine degradation byproduct deethylatrazine, accounted for 76% of the total number of pesticide detections, and atrazine and/or deethylatrazine were detected in all 19 lakes. In addition to atrazine, five lakes had detectable levels of metolachlor (Dual), one had detectable levels of alachlor (Lasso), one had detectable levels of simazine (Princep or Aquazine) and two had detectable levels of acetochlor (Harness or Surpass). Nine lakes had detectable quantities of the atrazine degradation byproduct deethylatrazine.

In almost all cases, the presence of these pesticides was directly attributable to agricultural activity. No lake in 2003 exceeded applicable numeric criteria, but several represent concerns based on numbers and amounts of pesticides present in the water column. Based on the number of different pesticides detected, Augusta Santa Fe Lake, Lake Shawnee, Milford Lake, Perry Lake, and Tuttle Creek Lake are of most concern. In terms of total maximum concentrations, Herington Reservoir, Perry Lake, and Tuttle Creek Lake (all water supply lakes) are of most concern.

Another interesting feature of pesticide sampling in 2003 seems to be that the reduced runoff and rainfall of the last few years has not reduced the number of detected pesticides, or their frequency of detection, to any significant degree. The same phenomenon was also noted last year (KDHE, 2002). During the last four years (2000-2003), which have been very much below normal precipitation years, 58.5% (53% to 62%) of lakes and wetlands sampled for pesticides had detectable amounts of pesticides present. The previous four years (1996-1999), which were not nearly as dry, show an average of 58.8% (51% to 70%) of surveyed lakes and wetlands having detectable amounts of pesticides present. The number of detectable pesticides was 5-6 each year during 2000-2003 and 6-7 each year during 1996-1999.

Table 14. Pesticides levels documented during 2003 in Kansas lakes. All values listed are in ug/L. Analytical quantification limits are as follows: atrazine = 0.3 ug/L, deethylatrazine = 0.3 ug/L, metolachlor = 0.25 ug/L, alachlor = 0.1 ug/L, simazine = 0.3 ug/L, and acetochlor = 0.1 ug/L. Only those lakes with detectable levels of pesticides are reported.

	Pesticide					
Lake	**Atrazine**	**Deethyl atrazine**	**Metolachlor**	**Alachlor**	**Acetochlor**	**Simazine**
Augusta Santa Fe Lake	1.10	0.50	1.20			
Banner Creek Lake	0.46					
Butler Co. SFL	0.64					
Chanute Santa Fe Lake	0.77					
Cheyenne Bottoms	1.20		0.34			
Clinton Lake	1.30	0.33				
Herington Reservoir	2.30	0.40				
Hillsdale Lake	1.20	0.53				
Kanopolis Lake	0.86					
Lake Kahola	0.33					
Lake Shawnee	1.50				0.10	0.78
Lone Star Lake	1.10	0.31				
Milford Lake	1.00	0.32	0.46			
Perry Lake	2.60	0.57	0.37			
Polk Daniels SFL	1.00					
Pony Creek Lake	0.70					
Tuttle Creek Lake	0.53	0.82	3.30	0.58	0.38	
Washington Co. SFL	0.69	0.35				
Wilson Lake	0.40					

Discussion of Nonpoint Sources of Pollution for Selected Lakes

Nine lakes were chosen for further discussion, based on the number and type of observed surface water quality impacts. A water body was chosen if 1) three, or more, parameters exceeded their respective chronic aquatic life support criteria/guidelines, 2) more than two parameters exceeded applicable acute aquatic life support criteria/guidelines, or 3) more than one parameter exceeded irrigation, water supply, livestock watering, or recreational criteria. Possible causes and sources of these documented water quality problems are considered below.

Butler Co. SFL has a moderately sized watershed (watershed/lake ratio = 33) with very little in the way of urbanized or tilled land (7% cropland). However, the lake is heavily nutrient enriched and almost continually hypereutrophic during the summer. The source appears to be livestock and livestock wastes within the watershed that are in fairly close proximity. This source, combined with the relatively shallow character of the lake ensure high trophic state conditions and numerous water quality related issues regarding nutrients and lake biological integrity.

Cheyenne Bottoms is a natural, although highly manipulated, wetland complex in central Kansas. The watershed contains abundant cropland and one permitted wastewater facility. At least some portion of the wetland's water quality problems also relate to variable and, sometimes, deficient hydrology.

Mined Land Lake 6 is one of numerous parcels of land strip mined for coal near the turn of the twentieth century in southeast Kansas. Although water quality signals related to this history have largely faded, this particular lake unit has recently shown a dramatic rise in nutrient levels and trophic state. This is also one of the two lakes discussed earlier concerning unusually high fecal coliform counts. Given the condition of the watershed (watershed/lake ratio = 7, and no agricultural activity or urbanized land), the source is not altogether obvious. One possibility concerns the recent renovations within this lake unit. About the time the water quality problems become apparent, renovations related to the toilet facilities were noted. There is a possibility the new facilities are leaking in some fashion, contributing to eutrophication and bacterial detections.

Ottawa Co. SFL has a relatively large drainage compared to the lake area (watershed/lake ratio = 90) with about 21% of the drainage in cropland. This situation, plus a relatively shallow depth, have created a highly eutrophic system that also supports over abundant macrophytic growth.

Quivera Big and Little Salt Marshes are natural wetland complexes in southcentral Kansas and they have begun to be impacted by hydrologic changes in the region resulting from groundwater extraction. Although similar in terms of overall water quality, far more land drains through the Little Salt Marsh. Regardless, both waterbodies typically show excessive nutrient enrichment and trophic state development (in terms of phytoplankton) than would likely occur under more natural watershed conditions, or with the reasonable application of best management practices.

Tuttle Creek Lake, in northcentral Kansas, is the second largest lake in the state. It has a predominantly agricultural watershed that extends into Nebraska (watershed/lake ratio = 98). The main water quality issues revolve around siltation, turbidity, nutrient enrichment, and pesticides which reflect the impacts from the watershed.

Webster Lake is a large lake in western Kansas with an extensive agricultural drainage (watershed/lake ratio = 210). At least one-third of this watershed is in cultivated land. Besides the nutrient/pollutant impacts from such an extensive watershed, the lake also experiences hydrologic impacts due to its use as an irrigation water source. This use means that the lake often is shallow enough to experience resuspension of bottom sediments, which can then further impact water quality.

Wilson Lake is another large lake in western Kansas with an extensive drainage (watershed/lake ratio = 144). In the case of this lake, however, pasture and rangeland dominate the downstream portion of the drainage. Low nutrient loads help Wilson Lake maintain low nutrient levels and a desirable trophic state. However, the high natural salinity of the water often exceeds consumptive use criteria. Otherwise, Wilson Lake is viewed as a lake with excellent overall water quality.

Taste and Odor/Algal Bloom Investigations During 2003 and Early 2004

From March 1, 2003, to February 1, 2004, six investigations were undertaken within the auspices of the KDHE Taste & Odor/Algae Bloom Program. The results of these investigation are discussed below. Three of the investigations dealt with fishkills, two were related to massive algae blooms and finished drinking water quality, and one was primarily an aesthetic complaint.

On June 3, 2003, staff from the KDHE Southcentral District Office visited East Emma Creek, in Northern Harvey County, in response to a fishkill. A white film was noted on the stream surface and multiple species and age classes of fish were dead. The water column was reported as having a dark "tea" color. Dissolved oxygen was measured at 1.6 mg/L while ammonia at the site was over 11.0 mg/L. The algae community was composed of a mixture of green flagellates and blue-green filamentous species. The community size was small-to-moderate and believed insufficient to contribute to the fishkill through diel dissolved oxygen changes. Runoff from a dairy lagoon was identified as a possible cause.

Beginning on or around June 5, 2003, Marion Lake began to experience a severe algae bloom with resultant drinking water taste and odor problems for the cities of Hillsboro and Marion. Samples collected for taxonomic analyses indicated a very large blue-green algae community composed of *Anabaena spiroides, Microcystis aeruginosa,* and *Aphanizomenon flos-aqua*. The dominant species was *Anabaena spiroides*. Cell counts approached 1.2 million cells per mL and chlorophyll-a was measured at 335 ug/L. Given the potential for toxin production by these species, Marion Lake was posted for recreational use advisories for most of June, 2003. This bloom is attributed to the excessive nutrient pollution the lake receives, exacerbated by the spring rains of 2003 which followed an extended dry period.

This combination of events likely resulted in the rapid "flushing" of accumulated nutrients and contaminants from the local watershed into the lake. As this slug of material moved through the lake in late spring and early summer, it is likely that it produced the abnormally large blooms observed. Until this material cycles through the system, further large algae blooms may be expected.

On June 17, 2003, samples were collected from Cheney Lake in response to another massive algae bloom. In addition to the threat to recreation and aquatic and terrestrial wildlife from algal toxins, the City of Wichita experienced severe taste and odor problems. The algal community was composed of a mixture of the blue-green species *Microcystis aeruginosa* and *Anabaena spiroides*. These species were co-dominant at the time the first samples were collected. The bloom conditions extended through the remainder of July, 2003. This massive bloom at Cheney Lake (100-to-500 million cells per mL: 10,300 ug/L chlorophyll-a in the bloom proper and 3,100 ug/L near the water intake at the surface) resulted from excessive nutrient inputs to the lake, likely exacerbated by the spring flush experienced in 2003 after an extended period of no runoff. This algae bloom ranks as one of the most severe documented by KDHE in Kansas.

On July 9, 2003, samples were collected by KDHE Southcentral District Office staff in response to a fishkill at Lake Waltanna, located southwest of Wichita, Kansas. Algae samples collected on that date indicated a very large blue-green community composed of *Anabaena spiroides* and *Aphanizomenon flos-aqua* (1.5 million cells per mL and 147 ug/L chlorophyll-a). Low morning dissolved oxygen levels (0.6 mg/L) were deemed the immediate cause of the fishkill. The ultimate cause, however, is attributed to excessive nutrient pollution of the lake. The suspected source of nutrients in the small watershed (<160 acres) is residential wastewater management in the form of septic systems. Lake Waltanna has had a history of similar fishkills over the years.

On July 21, 2003, staff from the KDHE Northwest District Office submitted photographs of a fishkill from a small lake in Smith County. No algae samples were collected, but the blood-red surface scums in the photographs were very suggestive of a massive bloom of Euglenoid algae. Blue decomposition pigments along the shores were also suggestive of a large blue-green bloom underneath the surface scums. Low dissolved oxygen levels were suggested as the most likely immediate cause of the fishkill. Agricultural runoff constituted the primary source of nutrients to the lake.

On January 14, 2004, in response to a citizen complaint, staff from the KDHE Southcentral District Office collected algae samples from a small urban lake in Arkansas City, Kansas. The lake had a massive blue-green algae bloom (13.7 million cells per mL in the bloom proper, an estimated 1-2 million cells per mL in the open water) composed of *Oscillatoria rubescens* (also known as *Planktothrix rubescens*). This bloom gave the lake an unusual and visually disturbing red-brown appearance, prompting the calls from the public. This particular blue-green algae is reported more commonly in winter and spring, rather than the more typical summer blooms common to most cyanophytes. City staff indicated they intended to close the lake to recreation until the bloom passed.

CONCLUSIONS

The following conclusions are based on the lake monitoring data collected during 2003.

1) Trophic state data indicated that only 22% of the lakes surveyed in 2003 had degraded, compared to their historic mean condition (i.e., their trophic state had increased). About 47% showed stable conditions over time, while 31% showed improved trophic state condition. Most of the improvement in trophic state can be attributed to the impact of prolonged drought on nutrient limited systems.

2) Over 70% of the documented water quality impairments in these lakes were associated with high lake trophic status. Other significant problems included low dissolved oxygen and high pH, chloride, sulphate, and high turbidity. Lake trophic state problems resulted primarily from excessive nutrient inputs from nonpoint sources, although some lakes actually showed improvement due to reduced runoff and pollutant loads over the last three years.

3) More than half of the lakes surveyed by KDHE had detectable levels of agricultural pesticides in 2003. As noted in previous years, atrazine was the most frequently detected pesticide. However, all detections in 2003 were below applicable water quality criteria. A new concern in Kansas is the increasing frequency (and magnitude) of detection of acetochlor. Given that acetochlor is now being marketed as a replacement for atrazine, this monitoring trend is likely to continue.

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LAKE DATA AVAILABILITY

Water quality data are available for all lakes included in the Kansas Lake and Wetland Monitoring Program. These data may be requested by writing to the Bureau of Environmental Field Services, KDHE, 1000 Southwest Jackson Ave., Suite 430, Topeka, Kansas 66612-1367, or calling 785-296-6603.

APPENDIX A

SOME RELATIONSHIPS OF VALUE TO LAKE MANAGERS

In the course of examining and analyzing lake water quality and physical data, two strong predictive relationships were developed which lake managers in Kansas may find of use in their work. The first deals with the relationship between mean summer chlorophyll-a and the expected maximum value one might anticipate for the summer. The second relationship deals with predicting the mean depth of Kansas lakes from the maximum depth to be found in the inundated stream channel just upstream of the dam.

Maximum Chlorophyll-a versus Mean Chlorophyll-a

KDHE lake network data were examined to determine the relationship between mean summer and maximum summer chlorophyll-a. Mean chlorophyll-a is a very common metric used to assign lake trophic state designation while the maximum summer chlorophyll-a can be interpreted as the "worst case scenario" for lake management purposes. Both metrics have distinct value in assessing the condition of lakes in terms of water quality, trophic status, and use attainment levels. In theory, the greater the mean algal biomass supported at a given nutrient level, the greater the maximum supportable level will also be.

Data from 1985 to 2003 were examined for 139 lakes deemed to have a sufficient number of surveys during the 18 year period of interest. The period of record mean and maximum values were calculated for each lake, transformed to linearize the data, and subjected to regression analysis. The result was a very good linear relationship between the two parameters as expressed by the equation given below.

$Y = 10^{((1.094 * \mathrm{Log}_{10}X)+0.146)}$, where

$X = \text{Chl-a}_{mean}$ in ug/L,
$Y = \text{Chl-a}_{maximum}$ in ug/L, and
^ = "to the power of."

$P < 0.001$
$R^2 = 0.95$

The above equation can be used for a number of lake management decision making efforts. For example, it can be used to forecast the worst case scenario for various lake trophic state conditions expressed as summer average condition. Used in reverse, as when an open water sample collected during a bloom might be considered as a potential maximum value, the equation can estimate the average summer condition under that assumption. The P value and R^2 for this equation are excellent, as is the residual plot for values in the typical chlorophyll-a range for Kansas lakes. However, at very high values of chlorophyll-a (>200 ug/L), the equation begins to underestimate the maximum value. A quadratic version of the above equation seemed to be preferable under such extremes of productivity and biomass. This alternate equation for extreme biomass situations is provided below.

$Y = 10\wedge((0.042*(Log_{10}X)^2)+(0.985*Log_{10}X)+0.209)$, where

$X = Chl\text{-}a_{mean}$ in ug/L,
$Y = Chl\text{-}a_{maximum}$ in ug/L, and
^ = "to the power of."

$P < 0.001$
$R^2 = 0.95$

These equations match other such relationships developed for other parts of the world, in terms of the ratio of maximum-to-mean chlorophyll-a (Dodds and Welch, 2000). While the ratios from other studies seem to match well with the ratio developed from this analysis, the data sets may not be reflective of the same time frames for data collection. Data collected as part of the KDHE program is meant to describe the long term mean conditions for Kansas lakes. Other studies may have primarily contained data reflective of more frequent sampling of lakes over a shorter time period. Therefore, the equations provided here would be best utilized when describing long term lake conditions rather than an individual summer. However, the similarities among the various models may suggest that the same relationship would apply regardless of time frame.

This ratio, for lake phytoplankton, ranges from 1.7-to-2.6 as a rule (Dodds and Welch, 2000). For the lakes in Kansas used to develop this relationship, the ratio ranged from 1.4 to 2.6 over three orders of magnitude in chlorophyll-a, increasing with the chlorophyll-a values. The mean for that range was 2.01. Therefore, a very rough rule of thumb might be applied to lake management. If algal chlorophyll-a averages "X" over a given period of time, the maximum nuisance value one might encounter during that time will be about "2X." If the lake in question is of very low trophic state, the maximum might be better estimated as "1.5X," while very productive systems might be better estimated as "2.5X."

Lake ecosystems with extreme chlorophyll-a values (>200 ug/L) should utilize the quadratic version of the formulae, whose maximum-to-mean ratio ranged 1.6-to-3.5 over three orders of magnitude. The mean ratio for the data set was 2.08 for the quadratic formulae. The maximum for such extreme systems would be roughly 3.5X the expected summer mean value.

Using the basic equation, for several summer mean chlorophyll-a levels, the following list provides calculated chlorophyll-a summer maxima for comparison. These numbers are reflective of the first equation, given the 10-100 ug/L mean chlorophyll-a range.

Long Term Summer Mean Chl-a ug/L Measured	Long Term Summer Chlorophyll-a Maxima ug/L Predicted
10	17
20	37
30	58
40	79
60	123
100	214

Maximum Lake Depth versus Mean Lake Depth

Mean depth can be a very valuable metric in lake management. A number of calculated metrics and models utilize mean depth, as do classification systems for regional lake analyses. Unfortunately, the actual determination of mean depth involves measurement of multiple depths along multiple transects, mapping of those results, and subsequent use of the resulting bathymetric map to calculate mean depth for the lake. Maximum depth, on the other hand, is fairly simple to determine while sampling a given water body. One simply travels along the dam, under the assumption that there lies the deepest area in the lake, and locates the maximum value using either a weighted line or sonar.

Both parameters have great utility in lake management, but it would save a great deal of time if lakes in a given region behaved according to a relationship that allowed estimation of one depth parameter from the other. Towards that end, depth data from Army Corps of Engineers (ACOE) projects in Kansas were obtained from their pre-impoundment surveys and informational brochures, as well as calculated mean depths from a number of special lake projects undertaken by KDHE over the last 20 years. Both data sets were analyzed against the maximum depths determined during the Department's periodic water quality surveys. In general, Kansas lakes have a strong relationship between mean and maximum depth, which should allow lake managers to estimate one value from the other with a fair degree of accuracy.

For 19 ACOE lakes, where mean depth data was readily obtained from pre-impoundment surveys or informational brochures, the following equation was generated. As the reported mean depth data was calculated when these lakes were new, while maximum depth data was measured at later dates, there is some possibility that sediment accumulation in the impounded stream channel could have exerted an impact on the relationship derived.

$Y = (0.422*X)-0.090$, where

$Y = Z_{mean}$ in meters, and
$X = Z_{maximum}$ in meters.

$P < 0.001$
$R^2 = 0.89$

For 10 smaller Kansas lakes, where mean depth profiles had been calculated as part of special investigations, the next equation was obtained. In this case, a square root transformation of maximum depths slightly improved the model.

$Y = (1.533*(X)^{0.5})-1.399$, where

$Y = Z_{mean}$ in meters, and
$X = Z_{maximum}$ in meters.

$P < 0.001$
$R^2 = 0.97$

Combining the two data sets resulted in the following "general use" equation for Kansas lakes.

$Y = (0.417*X)-0.148$, where

$Y = Z_{mean}$ in meters, and
$X = Z_{maximum}$ in meters.

$P < 0.001$
$R^2 = 0.92$

As one final exercise, a separate equation was developed from data collected from 14 Mined Land Lake Area units. This special effort was undertaken because these lakes derived from past strip mining tend to have steeper sides than are typical for most Kansas lakes. Therefore, it was deemed of value to see how the depth relationship varied in this particular sub-set of lakes in Kansas. As many lakes derived from gravel or other forms of material "mining" also typically have steeper sides than most Kansas lakes, the following equation may also have application in other areas of the state.

$Y = (0.515*X)+0.183$, where

$Y = Z_{mean}$ in meters, and
$X = Z_{maximum}$ in meters.

$P < 0.001$
$R^2 = 0.96$

The following list provides a comparison among the four predictive equations with respect to a maximum lake depth of 10.0 meters.

Equation Used	Maximum Lake Depth (m) Measured	Mean Lake Depth (m) Predicted
Large Lakes (ACOE data)	10.0	4.1
Smaller Lakes	10.0	3.5
General Equation	10.0	4.0
Mined Land Lakes	10.0	5.3

As a final comment, it should be noted that none of these analyses included wetlands or very shallow lakes (i.e., maximum depths typically less than 2.0 meters). Therefore, none of these models apply to very shallow systems.